WEIGHT ENFORCEMENT AND EVASION: OREGON CASE STUDY

Final Report

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by

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16. Abstract

This study examines the incidence of overweight trucks and its relation to regulatory enforcement activity. Addressed are questions of scale operations in relation to weight violations and the effectiveness of enforcement levels, automated preclearance systems and weigh-in-motion (WIM) technology. The study also compares state-by-state enforcement intensity and penalty levels to understand their relative effective deterrence.

To answer these question the Oregon Department of Transportation (ODOT) identified an I-5 freight corridor and two potential bypass routes to collect data from three WIM sites. Data collection occurred before, during and after an extended closure of the I-5 weigh station. The traffic volume data did not indicate evasion behavior on the bypass routes, nor diversion to I-5 during closure. Only the I-5 site exhibited a statistically significant pattern of increase in mean GVW from baseline through closure (.4%), and a decrease of 1.2% following reopening. The incidence of overweight vehicles on I-5 also exhibited a statistically significant increase from 2.27% before closure to 3.67% during closure and a decline to 3.19% after re-opening. Additional analysis explored the incidence of overloading among ODOT Green Light preclearance program participants. Green Light program participants were less responsive to scale closure than non-participant vehicles.

The study results suggest the following: 1) Relatively aggressive enforcement in Oregon (more weighings and stiffer fines for overweight violations) creates a climate where a single-site temporary suspension of weighing activity has less impact on trucking operations; 2) Weight enforcement activity at one site on I-5, the major West Coast freight corridor, may have little impact on interstate and international shipments; and 3) Green Light program participants may be either self-selecting compliant operators or, unwilling to jeopardize the benefits of the program by engaging in overloading.

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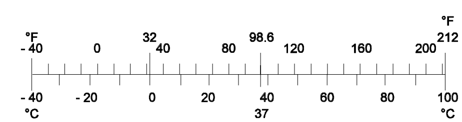
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

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EXECUTIVE SUMMARY

State weight enforcement data submitted to the Federal Highway Administration indicates that less than one percent of vehicles weighed are cited for weight violations. The low reported incidence of weight violations has lead to the question of whether automated preclearance systems ought to include weigh-in-motion (WIM) capabilities to screen for overweight vehicles. The literature on weight enforcement indicates that the low incidence of weight violation reflects a combination of factors, including the deterrent effect of enforcement activity as well as extensive scale evasion. To address these questions an experiment was conducted involving an extended closure of the northbound I-5 weigh station at Woodburn, Oregon.

Weight and volume data were collected from WIM sensors before, during and after scale closure over the course of four months. WIM data were collected from I-5 as well as two potential by-pass routes, OR 51 and Ehlen Road. The data did not indicate evasive behavior on the bypass routes. Diversion from the bypass routes to I-5 during the closure period was also limited. Vehicle count data for each bypass route showed an initial drop in volume following closure of the I-5 scale, but beyond closure and after reopening, the bypass route vehicle counts varied. Ehlen Road data indicated increasing volumes after an initial decline that then continued in an upward trend after reopening. Volumes on OR 51 never recovered to pre-closure levels after reopening of the Woodburn scale.

The mean gross vehicle weight (GVW) was calculated for each site to test for changes in overloading. Changes in mean GVW did not follow a consistent pattern across sites. Only the I-5 site exhibited the expected pattern of increase in mean GVW (0.4%) from baseline through closure, and a decrease of 1.2% following reopening. A difference in means test found the changes on I-5 to be statistically significant. The mean GVW on Ehlen Road increased 5.2% from baseline through closure, and then increased another 12.0% after reopening. The mean GVW on Highway 51 decreased from baseline through closure, and declined again after the I-5 scale reopened.

The incidence of weight violations was also examined. On I-5, the incidence of overweight vehicles increased from 2.27% before closure to 3.67% during closure, a gain of 61.2%. After the scale was re-opened the incidence of overweight vehicles declined to 3.19%, a reduction of 13.1%. All of these changes were statistically significant at the 95% confidence level.

Data from the I-5 WIM scale identified participants in ODOT's Green Light pre-clearance program. The incidence of overloading was greater for non-Green Light participants than Green Light participants for all phases of the study. The difference in the incidence of overloading between Green Light and non-Green Light participants was statistically significant only during the closure period. Thus it can be concluded that Green Light program participants were less likely to overload during scale closure than non-participant vehicles.

Results with respect to vehicle type show that class 13 vehicles exhibited a somewhat higher propensity to exceed the weight limit. Among Green Light program participants, vehicle classes 9 and 12 exhibited a significant upward shift in overloading during scale closure. Among non-participants, a significant upward shift was observed in class 10.

There are several possible explanations for the relatively modest shift in the incidence of overloading observed in this study. First, state-by-state weight enforcement data submitted to FHWA indicate that Oregon has pursued weight enforcement more aggressively than other states, with relatively more weighings and relatively stiffer fines for overweight violations (see Appendix A). In such an enforcement climate, a temporary suspension of weighing activity could be expected to yield less of a change in overloading practices.

Second, the study shows that participants in the Green Light program were less likely to overload during the scale closure period than non-participants. Thus the effect of the Green Light program on compliance deserves consideration. It may be that self-selection effects have resulted in a greater likelihood of the more compliance-inclined motor carriers choosing to participate in the program. Alternatively, program participants who see a time saving may be less inclined to jeopardize such benefits by engaging in overloading. Both of these interpretations may be relevant, given observations on the relative incidence of overloading by Green Light program vehicles before, during and after scale closure.

Third, it should be recognized that I-5 serves as the major West Coast freight corridor. For interstate and international shipments, weight enforcement will be encountered at a number of locations en route. The suspension of weighing activity at a single location can be expected to yield less of a response when it is known that enforcement activity continues to be maintained elsewhere along the corridor.

1.0 INTRODUCTION

Intelligent Transportation System (ITS) technologies have provided a means for states to maintain enforcement of commercial vehicle regulations in the face of rapid increases in the volume of truck traffic. Weight enforcement programs in a majority of states now employ weigh-in-motion (WIM) technology to screen potentially overweight vehicles and thereby reduce queues at weigh stations. Preclearance systems provide more comprehensive data recovery, resulting in near-automation of weigh station operations. With preclearance systems, vehicles equipped with Automatic Vehicle Identification (AVI) devices can have their registration and safety information automatically confirmed by weigh stations. When the data are in compliance and coupled with a check of size and weight compliance from highway speed WIM, vehicles are signaled to bypass the weigh station. The implementation of these technologies has facilitated an expansion of enforcement activity that is cost effective for both states and motor carriers.

In some instances automated preclearance systems are presently being installed that do not include a WIM component, thus allowing trucks to bypass weigh stations without actually being weighed. The argument for excluding WIM capability from preclearance systems is that the incidence of weight violations is very small. For example, weight enforcement data reported to the Federal Highway Administration (FHWA) indicate that less than one percent of the vehicles weighed are cited for a weight violation.

Eliminating WIM from preclearance programs on the basis of the low reported incidence of weight violations is questionable for several reasons. First, it is believed that evasion of weigh stations is extensive and that the true incidence of overloading is much greater than the weight citation data indicates. WIM data collected at Highway Performance Monitoring System (HPMS) sites, for example, shows as much as 20 percent of vehicles exceeding legal weight limits (*Church and Mergel 2000*). Second, it is argued that the existence of weight enforcement activity acts to deter overloading, and that eliminating this deterrence would lead to heavier loads (*Dal Ponte 2000*).

The purpose of this research was to provide evidence related to the above-mentioned concerns regarding evasion and enforcement effects through a controlled experiment. The experiment involved an extended closure of a weigh station located on northbound (NB) I-5 at Woodburn, Oregon. Weight and vehicle count data were recovered from WIM scales in the traffic lanes on I-5 at the site, as well as from two potential evasion routes located nearby. Data were collected before, during, and after the closure period. This allowed for analysis of changes in truck volumes on I-5 and the evasion routes, as well as changes in vehicle weights and the proportion of vehicles exceeding weight limits.

The remainder of this report is organized as follows. Chapter 2 reviews the literature on weight enforcement and evasion. Chapter 3 describes the study area and the data collection effort. The analysis of weight and vehicle count data is presented in Chapter 4. Findings and conclusions are reported in Chapters 5 and 6.

2.0 LITERATURE REVIEW

An understanding of the conditions facing weight enforcement agencies and the trucking industry helps define the scope of the literature relevant to this study. The conditions are largely regulatory, financial, behavioral and technical in nature. The growth of truck traffic and congestion in freight transportation corridors has triggered an interest in new methods for administering safety and weight regulations. Economic growth, lower transportation costs and transformations in manufacturing production methods have affected motor carrier behavior such that roadway congestion increasingly affects profitability in the trucking industry. The time-consuming inspections necessary at ports of entry and en route safety and weigh stations are being bypassed through the use of pre-clearance technology. AVI technology allows for a check on registration and safety data, but not axle or truck weights, by facility receivers. Used in combination with WIM technology the potential savings for motor carriers and administering agencies are substantial.

At the same time that more trucks then ever are on the road, the level of enforcement via manned and automated weigh facilities is also at record levels. The question thus posed is if regulatory enforcement were eliminated or diminished how would that affect load weights and road conditions? Is the low incidence of overweight trucks the result of greater enforcement activity? Secondarily, how is the motor carrier affected by the transitional state involving both automated and traditional weighing? Are the economic benefits gained by running overweight such that even with a greater chance of non-avoidance the trucker will operate over the legal limit?

The literature on motor carrier weight enforcement provides a measured response to the question of how enforcement levels affect behavior. The Transportation Research Board regularly devotes an issue of the Transportation Research Record to freight transportation and the United States Department of Transportation (DOT) publishes a periodic Comprehensive Truck Size and Weight Study. The *1995, 1997* and *2000 Comprehensive Truck Size and Weight Studies* from the FHWA identify a need for more analysis of enforcement levels and avoidance behavior due to safety concerns and the economic and roadway impacts of overweight vehicles. The more relevant material reviewed for this study from university and state department of transportation documents attempts to empirically relate enforcement levels and penalties with avoidance and overloading behavior. A summary of the relevant literature is included in Table 2.1.

Table 2.1: Main features of selected studies of weight enforcement and evasion

Reference	Study Description	Relations Examined	Findings	Recommendations
Bisson and Gould (*1989*)	Explores recognition of jurisdictional differences in enforcement levels, fines, and tolerances. The economic analysis attempts to develop a methodology for effective truck weight enforcement.	Comparison of potential revenues earned by overloading with expected cost of getting caught in New Brunswick Canada. Probability of detection estimated at 30 – 50%. Includes accounting for fine regime and the level of enforcement	Level of enforcement and compliance are tied to severity of punishment for violation. Market revenue from overloading exceeds cost of detection by as much as a factor of 10. Running various fine schedules results in a suggested $200 minimum graduated by amount of excess weight	Enforcement levels and severity of punishment should be increased substantially. Incremental enforcement costs are high and benefits minimal if fine structure does not increase. Need for severe punishment regime is tempered by political sensitivity.
Casavant and Lenzi (*1993*)	Appraisal of equity and effectiveness of fee/fine structure in minimizing the loss of road transport in State of Washington. Methodology: 1). Conceptualize the equity of the fee and penalty structure. 2). Determine impact of overweight loads on highways using Kip-mile combinations. 3). Economic evaluation of cost/benefit of overloading. 4). Develop recommendations for restructuring the fee and fine schedule	1). What are the financial impact on highways of overloads with estimates of overloads ranging from 5 % to 28%. 2). What effects the decision making process of motor carriers? 3). What is the most effective fine/fee structure producing cost-effective control of road damage?	Given the trucker's goal of maximizing profits, fee and fine schedules should be set to eliminate both the economic incentive and thus the occurrence of road damage. When quantified the economic incentive to overload is greater than the damage to roads at all trip lengths as presented in 30, 100 and 300 mile trip analysis models. The fine for overloading is a strong economic disincentive but is dependent on enforcement levels. Washington State fine levels are above the economic incentive to overload. A 10% capture rate for fines would serve to deter overweight operations.	Existing fee structure is too light at the heavier levels of overload; 50% increase at 10 Kips, and 15% at 30 Kips. Future research on: 1). Capture rates, 2). Tolerance in enforcement actions induces sloppiness in cost recovery.
Cunagin, Mickler and Wright, (*1997*)	Florida based case study assessing the degree of weigh station avoidance through corridor and by-pass enforcement activities.	Examines permanent site vs. temporary bypass weight inspections. Comparison of WIM data to monitoring site data. All potential bypass routes covered by study.	Intense enforcement reduces violation rate. Vehicles attempt to bypass permanent weigh stations. At fixed scales .8% of trucks were overweight, while 19% were overweight at bypass route locations. Higher number of violations observed on weekends, when stations are normally closed. Carriers responded to increased enforcement within 3 days of study initiation.	Each weigh station area should be clearly defined by a cordon. Regular (quarterly?) monitoring effort should be undertaken to identify evasion patterns. Permanent WIM installation on bypass routes can be used to determine patterns in scale avoidance. Enforcement level should be related to value of citations and avoided infrastructure damage.

Table 2.1 (continued): Main features of selected studies of weight enforcement and evasion

Reference	Study Description	Relations Examined	Findings	Recommendations
Federal Highway Administration (*1995*)	Study emphasizes the national environment for enforcement activity, changing Truck Size & Weight regulations, and costs and effectiveness. Focus on effective regulatory environment for industry and enforcement community (uniform, simple and reasonable).	1). Technical relationships of policies to all overweight operating issues. 2). Challenge of quantification of overweight problem and enforcement levels. 3). Vehicle specification and differences in enforcement. 4). Technological and operational impacts on enforcement activities.	Relates results of case studies listed here and includes Cottrell, B.H. 1992 (FHWA/VA-93-R2): two bypass route sites experienced 11% and 14% overweighing and non-enforcement WIM data indicated 30-60% higher loadings than static scales with enforcement operations. Quantification through the use of WIM and advance vehicle identification technology increases productivity of enforcement activities. Legal, judicial and penalty sanctions summarized in support of other findings listed here.	Additional evaluation of enforcement mechanisms and strategies recommended through a comprehensive research approach that address all potential policies and cost-effectiveness. Recommends quantification of overweight problem, enforcement strategies and associated costs. Results of enforcement research could impact TS&W provisions, gross vehicle weight limits, other weight provisions and additional technical and regulatory tools.
Federal Highway Administration (*1997*)	Comprehensive national study examines components and characteristics of State Enforcement Programs (SEPs).	The degree of noncompliance, fines, penalties, and judicial and legislative support varies greatly by state. Reviews enforcement strategies using fixed and mobile/WIM facilities.	Numerical measures of enforcement have increased since 1982 (static weightings 1985 - 97,000, 1995 – 111,620. Some state programs are more comprehensive than others to include WIM and static scales, and fixed and mobile. Scale avoidance is a problem at fixed facilities.	Mobile enforcement provides a higher level of deterrence. WIM technology improves efficiency and effectiveness of weighing operations and, coupled with photo imaging, aids in assessing civil penalties.
Federal Highway Administration (*2000*)	Explores truck size and weight enforcement issues at the national level. Includes a review of past and current federal and state programs, state enforcement activity, a summary of case studies of state practices, and efforts to improve administration and enforcement.	Describes historical evolution of size and weight regulations. Poses the question: "What is a reasonable level of enforcement given the uniqueness of each state's laws and resources?"	State enforcement efforts are generally increasing in terms of fine and penalty schedules. WIM technology facilitates enforcement in 28 states. The percentage of trucks weighed that are cited is very small and varies little over time (less than 0.4% in 1995). Offloading or load shifting requirements are a strong enforcement mechanism and are increasing in use. Evasion continues to be a problem, but is more related to safety issues than overloading.	Mobile safety and weight enforcement levels should be expanded. A uniform federal or regional weight limit and permit schedule may be desirable. Broad recommendations include: 1. Quantification of the nature and extent of overloading. 2. Plans and strategies to combat overweight vehicles. 3. Application and evaluation of enforcement techniques and assisting technologies.

Table 2.1 (continued): Main features of selected studies of weight enforcement and evasion

Reference	Study Description	Relations Examined	Findings	Recommendations
Fekpe and Clayton (*1994*)	A model is developed describing the maximum potential violation rate as a function of the intensity of weight enforcement and other transport regulations. Model is estimated using enforcement data from Manitoba and Saskatchewan.	The model is an exponential function that estimates the maximum violation rate for a given inspection intensity. The constant depends on the method of enforcement (fixed location scales vs. mobile patrols).	Weight violation rates decline exponentially with inspection intensity. Estimated violation rate at zero inspection ranges from 4% (permanent scales) to 38% (mobile patrols). Mobile patrols are estimated to be 30 times more effective than continuously operated permanent scales in detecting weight violations. Randomly operated scales are 8 times as effective in detecting violations. Probability of detection at permanent scales with high operation levels is reduced by 5% with the availability of bypass routes.	Increasing the probability of detection requires increasing inspection capacity. Additional enforcement activity is suggested by the availability of by-pass routes, which reduce the truckers perceived detection probability.
Grundmanis (*1989*)	Weigh station avoidance and enforcement strategies case study on I-94 corridor in Wisconsin. Westbound traffic was monitored on I-94 and all bypass routes. Monitoring of truck stops and rest areas was undertaken during heavy enforcement activities.	Study attempts to quantify scale evasion by motor carriers for three levels of enforcement.	From enforcement level 1-3 the percentage of overweight trucks on I-94 decreased below the baseline by 6% to 27% to 34%. The percentage of overweight trucks on the bypass increased 140% from baseline at level 1, 70% at level 2 and decreased 13% at level 3. A greater number of trucks in violation (weight, driver, safety…) were observed on the by-pass routes.	Knowledge of relationship between enforcement level and degree of avoidance can be use to optimize enforcement strategies. Enforcement activities should utilize WIM technology to collect, process and report avoidance data on by-pass routes. Pavement designs should take scale evasion into account.
Hanscom (*1998*)	Paper assesses nationwide compliance trends in response to alternative enforcement actions.	Identifies numerous Measures of Effectiveness (M.O.E.s) to quantify success of enforcement activities (i.e., frequency and severity of gross weight violations).	Supports the need for additional studies based on identified enforcement practices across United States.	Supports standards for data collection (M.O.E.s) at regional, state and corridor level. Recommends data collection in compliance with known shipping patterns across all time periods and all roadway functional classes.

Table 2.1 (continued): Main features of selected studies of weight enforcement and evasion

Reference	Study Description	Relations Examined	Findings	Recommendations
Hildebrand (*1990*)	A theoretical economic model provides a dynamic "strategic framework for analyzing the economic outcome of different levels of fines and enforcement efforts." Uses "game theory" to determine the "equilibrium level of weight regulation compliance given a set of enforcement parameters."	In a two-player non-zero sum game, the trucker's revenue gains are balanced against the government's loss, and the government's cost of enforcement is balanced against the gain to truckers. Financial penalty for overloading, associated revenue gain and cost of compliance are the trucking parameters. Extra damage to pavement, revenue collections from violators and scale operating costs are the government parameters.	Usual result of modeling, given the non-cooperative relationship, is a negative or zero payoff to the players, the best possible result. The modeled equilibrium point may "serve as a useful tool for assessing the environment created by weight regulation policy."	Game theory model supports removing the economic gains of overloading by illustrating how penalties should be structured. Provides an economic framework to analyze results of penalty system and scale operations.
Pigman and Deacon (*1989*)	Focuses on avoidance of active weigh stations on main highways in Kentucky. Weekday only data from manual classification counts, automatic vehicle classifier counts, and WIM counts.	Comparison of truck counts and weights during open and closed time periods of permanent weigh stations.	On bypass routes with inspection stations open: 1) Number of trucks increases; 2) Proportion of all vehicles that are large trucks increases; 3) Proportion of "heavily laden" trucks is greater; 4) Proportion of large trucks in the study area corridor is greater.	Scope of study limits conclusions. Evidence suggests temporary opening of truck-inspection facilities affects avoidance behavior. Degree of compliance was not measured (heavily laden vehicles were considered as those exceeding bridge formula limits from WIM data).
Paxson and Glickert (*1982*)	A national economic study of incentives (benefits) and disincentives (costs) of truck overloading that includes enforcement procedures.	Examines benefits of overloading using decrease in transportation costs per unit with increase in cargo weight measurement. Fine and penalty structures "are combined with the probability of being weighed" for understanding of potential gains for carrier. Net benefit is based on costs vs. incentives.	Current enforcement programs and fine structures are inadequate. Probability of being weighed is low. Costs per ton-mile decrease dramatically and cost per mile increase slightly as load weight increases (based on 1979-80 National Motor Transportation Data). Additional data from *Overweight Vehicles: An Inventory of State Practices*, FHWA, 11/79/00.	Permits for legal overweight runs should reflect the pavement damage costs. Fines should be high enough to act as deterrent and cover cost of impacts. Probability of detection and level of enforcement should be balanced to deter overloading.

Table 2.1 (continued): Main features of selected studies of weight enforcement and evasion

Reference	Study Description	Relations Examined	Findings	Recommendations
Titus (*1996*)	Paper examines the trucking industry enforcement burden as a cost of compliance. Estimates the amount and value of time spent on enforcement activities.	Weight and safety compliance in relation to evasion costs. Anecdotal claims of high evasion rates in trucking industry.	Estimates time and costs of weight enforcement activities 1989-1991 as 10 million hours resulting in $166-$282 million expense. Carriers most in compliance bear greatest costs.	Implications that the industry born cost of enforcement will affect carrier behavior. Incentive argument in favor of Intelligent Transportation System - Commercial Vehicle Operation programs.
Walton and Yu (*1983*)	Case study of regulations, enforcement agencies and characteristics of overweight vehicle movement in Texas. Methodology is based on pavement and highway rehabilitation costs comparing actual conditions with 100% compliance condition.	Study emphasizes economic effects of overweight freight movement and efficiency of fine and permit structure. Characterizes size and weight violations and permits and cost of such operations to the state. Sample was restricted to 9 months in 1980.	Overweight vehicles classified as illegal, permitted and special dispensation. Variables include category of violation, monthly frequency and location, highway class, vehicle body type, permit category, and amount overweight. Used additional data from the annual truck weight survey. Estimates a trucking industry net savings of $1.23 billion over 20 years given current (1980) operating conditions.	Better judicial/statutory enforcement mechanisms are needed. Focus on bulk haulers. Fine structure must be revised to decrease incentive. Higher enforcement levels, and complimenting budgeting, needed. A more effective weight survey program would aid in planning, design and management of state highway system.

<u>Key to abbreviations</u>:
Kips –A non-metric measurement unit used for weighing trucks (Kilo Pounds)
FHWA – Federal Highway Administration
WIM – Weigh In Motion

2.1 REGULATION

The economic and regulatory forces at work in the enforcement of weight regulations are the focus of much prior research. The FHWA has found that the degree of noncompliance, fines, penalties and judicial and legislative support varies greatly by state (*FHWA 1997*). Nominal levels of enforcement have increased substantially since 1985, a large proportion of which is the result of the increasing use of WIM scales for screening overweight vehicles (Table 2.2).

Table 2.2: Trucks weighed and citations issued

	FY 1985	FY 1989	FY 1995	FY2000
Trucks weighed (Excluding WIM)	97,331,000	124,687,000	111,620,000	100,103,108
Trucks weighed by WIM scales	7,903,000	22,263,000	57,948,000	92,888,114
Weight citations	664,000	692,700	655,000	653,310
Violation rate	0.007	0.006	0.006	.007

The FHWA concludes that safety and weight enforcement levels should be greater. Given the variation in state commitment, a uniform Federal or regional weight limit and permit schedule may be desirable (*FHWA 2000*). Recognizing the unlikely adoption of such, the FHWA makes a broad set of recommendations that relate to this study. They include:

- Quantification of the nature and extent of overweight vehicles,
- Plans and strategies to combat overweight vehicles, and
- Application and evaluation of enforcement techniques.

Recent statements from the Federal Motor Carrier Safety Administration (FMCSA) also support additional research in this field. The responsibility and role in addressing truck safety is established as critical to all who are active in the transportation and applicable legislative fields, from shippers and law enforcement to the insurance community and federal and state government agencies (*Dal Ponte 2000*).

2.2 ECONOMICS

The economic importance of weight enforcement activities is reinforced by the need to preserve Federal and State highway investments. The impact of overweight vehicles on roadway conditions is well documented. The increase in vehicles weighed by fixed and WIM scales is occurring primarily on Federal and State highways, where roadbeds are engineered to support heavier axle weights. The detrimental impacts and associated costs of heavy vehicles on roads engineered to a lesser standard are also well known. Fepke and Clayton (*1994*) and Grundmanis' (*1989*) support of additional mobile scale deployment on secondary roads reinforces the need to examine enforcement levels and their relationship to avoidance behavior.

Bisson and Gould (*1989*), Hildebrand (*1990*), and Paxson and Glickert (*1982*) conclude that current penalty and fine structures have a minimal effect on carrier behavior. At current penalty levels total vehicle operating costs per ton-mile decrease dramatically, while the cost per mile increases slightly as load weight increases. Depending on the probability of detection and level of enforcement the economic gain to truckers who are risk-inclined is consequential. Market revenue from overloading can exceed the cost of detection by as much as a factor of 10 (*Bisson and Gould 1989*). Using a game theory model, Hildebrand (*1990*) explores the "equilibrium level of weight regulation compliance given a set of enforcement parameters" (p. 442). His model balances carrier revenue gains from overloading against the government's loss, and the government's cost of enforcement against the gain to carriers. Hildebrand's findings support removing the gains of overloading by illustrating at what level and how penalties should be structured.

The FHWA (*2000*) identifies three mechanisms that negatively influence motor carrier utility gains from overloading. The first two are on-the-ground enforcement actions while the third is based on administrative actions. Immediate offloading at the weigh-station influences on-time performance and necessitates an additional trip by the carrier. The time-consuming expense of load shifting, to impact axle weight distribution, is a successful enforcement technique recommended by the FHWA. The use of relevant evidence, as in Minnesota, allows for the documentation of overweight violations to be used in civil court proceedings to recover damage costs. The FHWA and Walton (*1983*) suggest better judicial and statutory enforcement tools to combat overweight operations.

Cunagin (*1997*), Grundmanis (*1989*), Fepke (*1994*) and the FHWA (*2000*) assess the effectiveness of fixed location versus portable scales and recommend mobile safety and weight enforcement activities as a stronger deterrent to avoidance behavior. Observed levels of weight violations at fixed scales range from 0.8% to 4% at various enforcement levels. At portable scales the level of weight violations varied from 3% to 58%. Evidence indicates that portable scales are more effective at capturing weight violators. Mobile and portable scales are more costly to operate than fixed scale facilities per vehicle and suffer from poor safety characteristics for the enforcement officer, drivers and vehicles. Nevertheless portable scales are highly flexible in terms of secondary and bypass route deployment.

Cost recovery is another theme identified in many studies, and it is one of many suggested tools that are opposed by the motor carrier trade. Hildebrand (*1990*) and Paxon (*1982*) recommend full recovery of pavement damage costs through permit and fine revenue. Industry opposition has successfully prevented the widespread adoption of many of the enforcement mechanisms supported in the literature. States recognized for having innovative and strong enforcement programs include Georgia, Minnesota, Oregon, and Wisconsin (*FHWA 2000*). While enforcement tools are well known the question remains, "What is the reasonable level of enforcement given the uniqueness of each state's laws and resources" (p. 7-4).

2.3 QUANTITATIVE ANALYSIS

Empirical research in the form of site-specific studies in Wisconsin, Kentucky, Texas and Florida provide evidence of the relationship between enforcement practices and evasion.

Additional research by Hildebrand, Hanscom, and Fepke and Clayton provides findings that respond to the need for quantifying enforcement and violation levels and examining evasion behavior.

Inherent in the study of enforcement and evasion is the risk associated with detection through weight enforcement. Fepke and Clayton (*1994*) attempt to gauge the "perceived probability of detection" to evaluate the effectiveness of alternative enforcement methods. Using an exponential function that estimates the maximum weight violation rate for a given inspection capacity, their upper bound limit model expresses that rate as a function of inspection intensity. Violation rates were regressed on corresponding inspection rates with a coefficient based on the method of enforcement and the definition of "in-violation." Their findings indicate that inspection intensity has an influence on the probability of detection; that is, low violation rates are associated with a higher probability of detection, which is associated with a higher inspection rate. Mobile patrols are estimated to be 30 times more effective than continuously operated permanent scales, and randomly operated scales are eight times as effective in detecting violations. There are additional indications that "the availability of alternate routes reduces the perceived detection probability by at least 5%" from the base strategy and that operating schedules and location type affect the behavior of motor carriers (p. 152).

Fepke and Clayton's work is supported by case studies in Wisconsin and Florida (*Grundmanis 1989; Cunagin 1997*). The methodology in each case was similar:

- The study areas were interstate corridors near state borders.
- The corridors were associated with long haul traffic.
- Each site had fixed scales and/or WIM equipment in place.
- Bypass and secondary routes were either limited by geography or clearly identified.
- Bypass and secondary routes were monitored with either WIM or portable scales.

In Wisconsin, only westbound carrier traffic was monitored, reflective of freight flows from Chicago through Wisconsin to Minneapolis. In Florida monitoring was multi-directional capturing flows from and to Georgia associated with Jacksonville and the surrounding farm, pulpwood and ocean port sites. Both studies employed four degrees of enforcement, from a zero baseline level to saturation enforcement of all bypass routes, waysides and rest stops. The results indicate the following:

- In Wisconsin observed violation rates were reduced by intense enforcement activity. At Enforcement Level 1, violation rates were reduced by 6% from base line; at saturation enforcement levels, violation rates were reduced by 34%.
- At greater enforcement levels vehicles attempted to bypass permanent weight enforcement stations.
- Truckers were quick (within several hours) to respond to varied enforcement levels. At moderate enforcement levels in Wisconsin no diversion occurred on a major bypass route, but a high percentage of diversion occurred on the secondary bypass routes.
- The higher the degree of enforcement, the greater the dispersion of vehicles over the study area.

- Avoidance behavior was more attributable to safety and driver violations than weight violations.

Additional findings from Wisconsin conclude that “normal” scale avoidance disproportionately impacts pavement life on major bypass routes because these facilities are not designed to carry heavy loads.

The literature reveals that over the last two decades the federal and state regulatory environment has shaped weight enforcement and evasion tactics. This is reflected in the Federal Highway Administration’s transition to a maintenance and management orientation that has influenced the direction of research. Research on safety and pavement life service issues is considerable. The study of weight enforcement in terms of cost effectiveness and weight-law compliance is less abundant.

In summary, the literature indicates that overloading and evasion activities are sensitive to weight enforcement practices. More intensive enforcement is found to result in less overloading. The presence of enforcement is also found to be quickly communicated, resulting in fairly extensive evasion. Thus, while enforcement data nominally indicate that less than one percent of vehicles exceed weight limits, there is also evidence that enforcement activity is capturing as few as ten percent of weight limit violators.

Empirical studies of weight enforcement have been limited to specific sites. One drawback of site-specific analysis is the difficulty of inferring results to larger settings. Thus, such studies provide only indirect evidence on the effectiveness of statewide enforcement programs. They also fail to take into account the deterrent effects of penalties for weight violations. As a result, the site-specific studies are only marginally useful at the program level. These decisions depend more on state-level rather than site-specific analysis (see Appendix A).

3.0 STUDY AREA

3.1 I-5 CORRIDOR CHARACTERISTICS

The following study area selection criteria were identified as necessary for investigating the effect of enforcement levels on compliance:

- A highway corridor characterized by high commodity flows;
- The existence and availability of monitoring facilities;
- Identification of potential bypass routes;
- Natural boundaries or geographic features to limit alternate bypass routes.

Northbound Interstate 5 through the Northern Willamette Valley of Oregon was identified as fitting the site selection criteria. Interstate 5 traverses western Oregon and is the main north/south commodity corridor. The Oregon segment is part of the larger international I-5 route that encompasses Mexico, California, Oregon, Washington and British Columbia, Canada. This study focuses on that portion of I-5 that travels the length of the Willamette Valley from central to northern Oregon (see Figure 3.1).

3.2 STUDY AREA CHARACTERISTICS

The study concentrated on the area surrounding the Woodburn Port of Entry (southbound) and the Woodburn WIM sorter and scale station (northbound). I-5 and two potential bypass routes, Hubbard Road (Highway 51) and Butteville Road were monitored using WIM technology (see Figure 3.2). Each monitoring station was capable of gathering data on truck volume, class, gross vehicle weight, and weight by axle. Site 1, the I-5 northbound Woodburn scale is a permanent weigh station facility that is operated regularly by the Oregon Department of Transportation (ODOT). The northbound Woodburn facility contains WIM and static scales.

Site 2 is located to the east of I-5 on Hubbard Road, just south of its intersection with State Highway 51. Site 3 is located west of I-5 on Ehlen Road within ¼ mile of Butteville Road. For this study permanent WIM installations were completed at each bypass site. These sites have been identified by ODOT as potential bypass routes. Motor carriers can exit I-5 at Highway 214/211 and may thus travel north on Butteville Road to the west or Boones Ferry and 99E/Hubbard Road (H51) to the east. The bypass routes reenter I-5 at Ehlen Road.

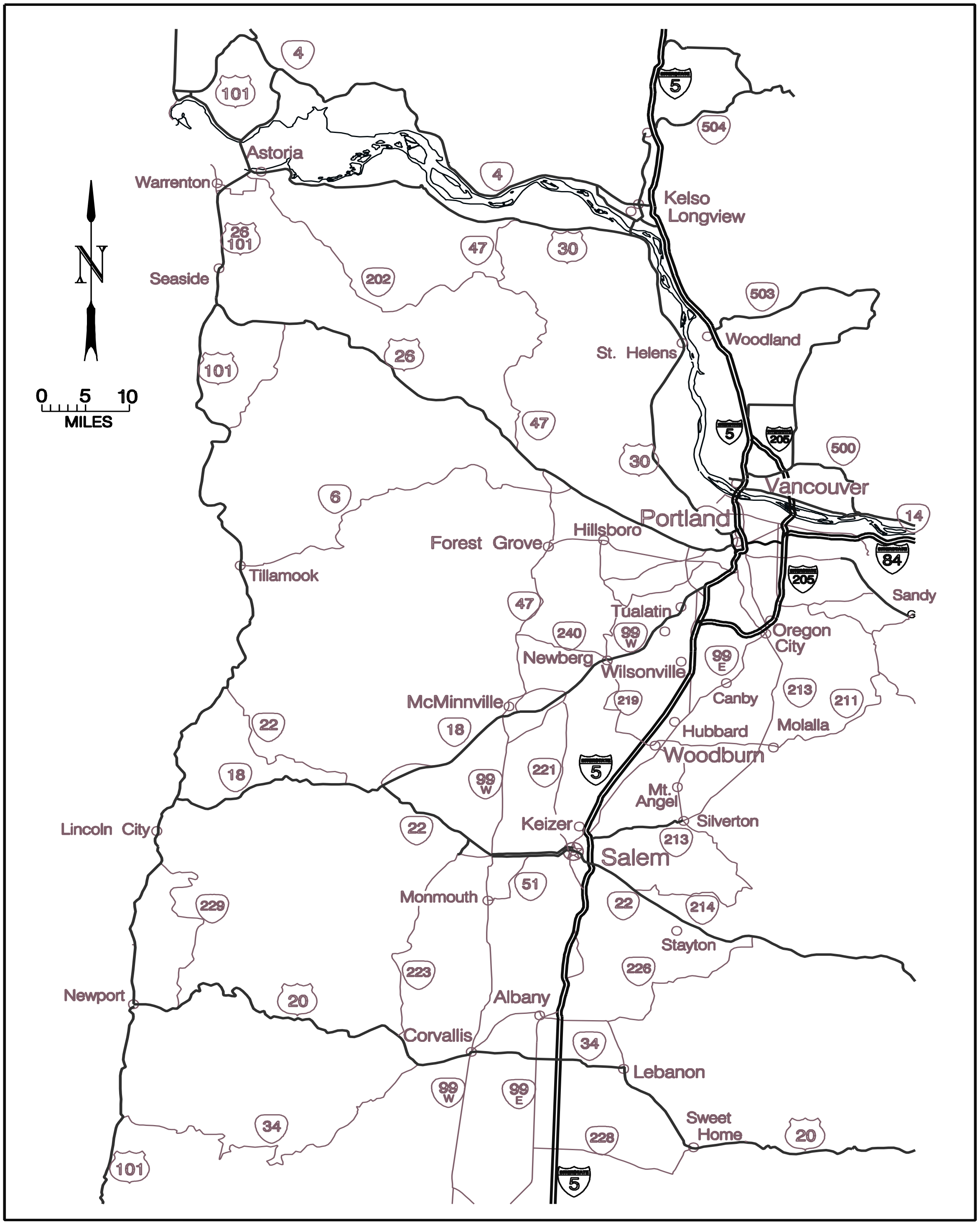

Figure 3.1: Regional map of NW Oregon & Washington

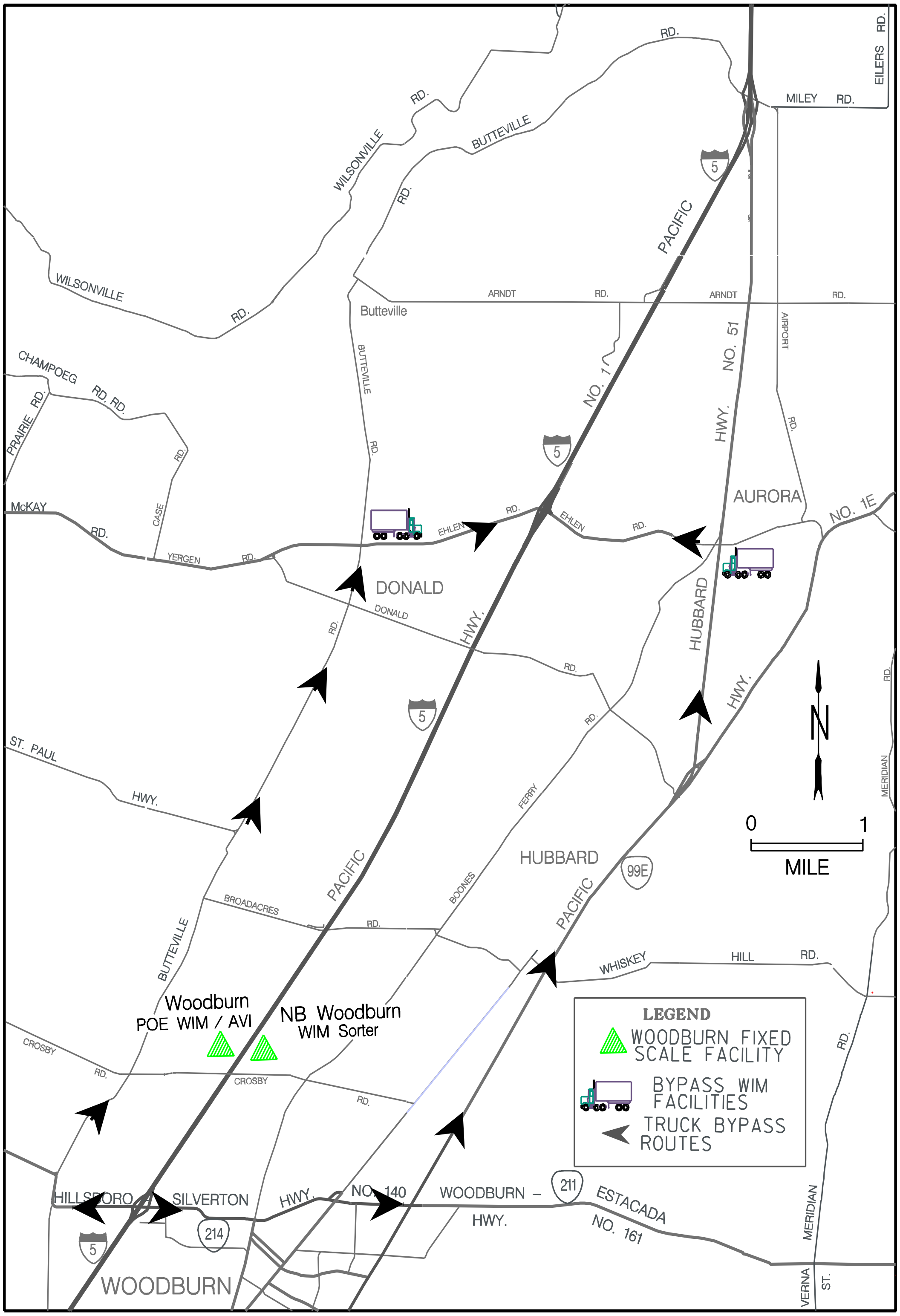

Figure 3.2: I-5 Corridor study area

3.3 COMMODITY FLOWS

Portions of ODOT's Region 1, Portland-Metro, and Region 2 are included in the study area. Region 2 includes the north and central coast, the west slope of the Cascade Mountains, and the southern and central Willamette Valley. The study corridor weigh facilities are on the border of the two regions. Regions 1 and 2 contain the majority of Oregon's population. Thus commodity flows are higher than other parts of the state and are consumer products oriented.

3.4 SCALE OPERATIONS

ODOT operates a pre-clearance facility at the northbound (NB) Woodburn weigh station. Trucks that have "Green Light" technology are signaled to bypass the weigh station at highway speed after passing an AVI-triggered computer assessment of registration and safety data and a WIM check of size and weight. Over 1,700 motor carriers are enrolled in this program in Oregon with over 18,000 transponders deployed in their fleets. At the NB Woodburn facility the number of trucks weighed and checked by the preclearance system is nearly as many as those weighed on the static scales (see Table 3.1). Participants in the Green Light program include:

- Less than truckload (LTL) fleets, such as UPS, Federal Express and USF Reddaway;
- Grocers and local freight haulers, such as Safeway, United Grocers, May Trucking and Gordon Trucking;
- Oregon-based companies with broadly distributed facilities, such as Les Schwab, JR Simplot, and Willamette Industries.

Table 3.1: Truck weighings in 2000

Weigh Station	Static Scale Truck Weighings in 2000	Trucks Checked and Weighed by WIM/Green Light System in 2000
Woodburn Weigh Station Interstate 5 Northbound	95,348	88,886

These companies operate distribution and warehousing facilities within the study area. The I-5 NB scales capture the movement of these carriers into the Portland Metropolitan area from their facilities to the south and the natural resource based facilities located in the coast range and Cascades.

4.0 METHODOLOGY

4.1 DATA COLLECTION

To assess the relationship between evasion and enforcement in the study area, data were collected from the three WIM sites over the course of four months in 2001. Data fields included speed, vehicle class, gross vehicle weights (GVW), axle counts and axle weights, length, and distance between axles. Additional data from the I-5 northbound scale included data identifying Green Light program participants. On May 19, the I-5 northbound weigh station was closed and the off-ramp was barricaded. The I-5 in-road WIM scale continued to function as the mainline data collection point. The weigh station remained closed as reconstruction of off-ramp paving occurred through July 31. After reopening of the I-5 northbound weigh station on August 1, data collection continued through August 18. This collection schedule provided a baseline of data before closure, a sizable data set during closure and a return to normal enforcement operations after closure.

4.2 DATA PROCESSING

Approximately 5000 trucks per day passed over the northbound I-5 in-road WIM scales, generating a data set exceeding 600,000 records for the study period. Combined with the bypass route data, the large number of records required considerable processing. To account for potential WIM sensor and classification inaccuracies, the data were sorted by vehicle class, speed, number of axles and length. Vehicle records were deleted from the database in the following circumstances:

- Speed was less than five miles per hour or greater than 100;
- Length was less than 18 feet or greater than 120;
- Number of axles was less than two or greater than nine.

The data was organized by class, gross vehicle weight and axle spacing to determine overweight violation levels. ODOT's *Truck Weight Limits* publication was used to set weight limits in pounds according to the number of axles per vehicle and axle spacing (*ODOT 2001*).

ODOT issues Extended Weight permits to vehicles over 80,000 pounds and under 105,500 pounds. Without examining permit records it was impossible to identify legally operating overweight vehicles. Most of these permitted vehicles had more than five axles. Six axle and greater vehicle occurrences numbered about 128,500. Given the lack of Extended Weight permit data, all vehicles with more than six axles (Classes 14-19) were removed from the data set. In addition, vehicles in Classes 1, 2, 4 and 7 were deleted, given that their loads would not be expected to change with weight enforcement levels. (See Appendix B for the definitions of vehicle classes.) The final data set consisted of approximately 351,000 records.

Supplementary data fields were created to aid in sorting and analysis. They included a study period variable (1=before closure, 2=during closure, 3=after closure) and a summation of total axle spacing per vehicle for application of weight limits outlined in tables from ORS 818.010. Additional dummy variables were created for overweight vehicles, for I-5 recorded AVI participants, and for overweight AVI participants.

4.3 DATA ANALYSIS

To assess how motor carriers responded to enforcement, three approaches were pursued through data analysis: changes in volume, changes in vehicle weights, and changes in the proportion of overweight vehicles. Changing evasion patterns would be exhibited through increases or decreases in overweight and non-overweight vehicle counts at each site. For example, one would expect the volume of traffic to <u>increase</u> on I-5 during closure as vehicles shift off the bypass routes knowing that the static scale is closed. The opposite trend in volumes would be expected for the bypass routes. A volumetric graph representing this pattern is shown in Figure 4.1.

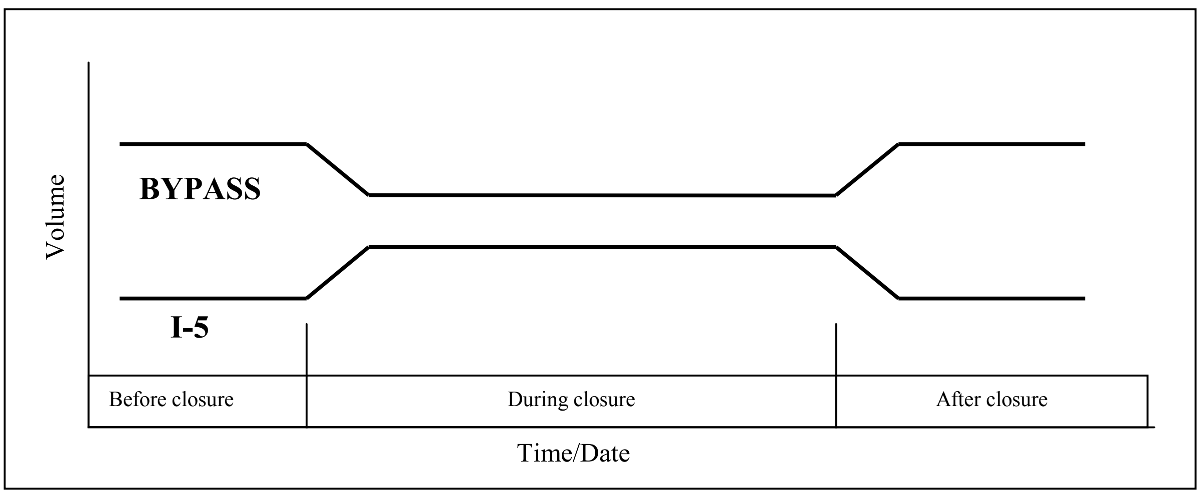

Figure 4.1: Expected traffic volume patterns

Truck volumes were calculated and graphed by site and by vehicle class. The average daily frequency was calculated for each site, for each study period, and compared between each study period (before vs. during, during vs. after, and before vs. after).

Variations in gross vehicle weights per site and per period illustrate additional motor carrier operational modification. Variation was estimated through a comparison of mean gross vehicle weights. Further analysis included a comparison of overweight vehicles by site, class and AVI status, using a significance test of proportionality. To determine whether the change in proportion of overweight vehicles was statistically significant, the confidence interval for the change was calculated as follows:

$$\text{CI} = P_B - P_D \; {}^{+}\!\!/\!_{-} \; 1.96 * s.e(p_B - p_D) \qquad \textbf{(4-1)}$$

where

$$s.e.(p_B - p_D) = \sqrt{\frac{p_b(1-p_b)}{n_b} + \frac{p_d(1-p_d)}{n_d}} \qquad \textbf{(4-2)}$$

and

$$P_B = {}^{r_B}\!/\!_{n_B} \qquad P_D = {}^{r_D}\!/\!_{n_D} \qquad \textbf{(4-3)}$$

$s.e.$ =	standard error
P_B =	proportion of overweight vehicles before closure
P_D =	proportion of overweight vehicles during closure
r_B and r_D =	the number of overweight occurrences before and during scale closure
n_B and n_D =	the total number of vehicles before and during scale closure

5.0 FINDINGS

5.1 EVASION

The evidence of diversion was limited. Vehicle counts showed considerable variation independent of controls and expectations. On Highway 51 the number of vehicles decreased two weeks after closure and continued to fall through the closure period and after reopening (see Figure 5.1). This change in volume was also reflected in the average daily volume, where the mean number of vehicles went from 146 per day before to 82 during and 49 after closure (see Table 5.1).

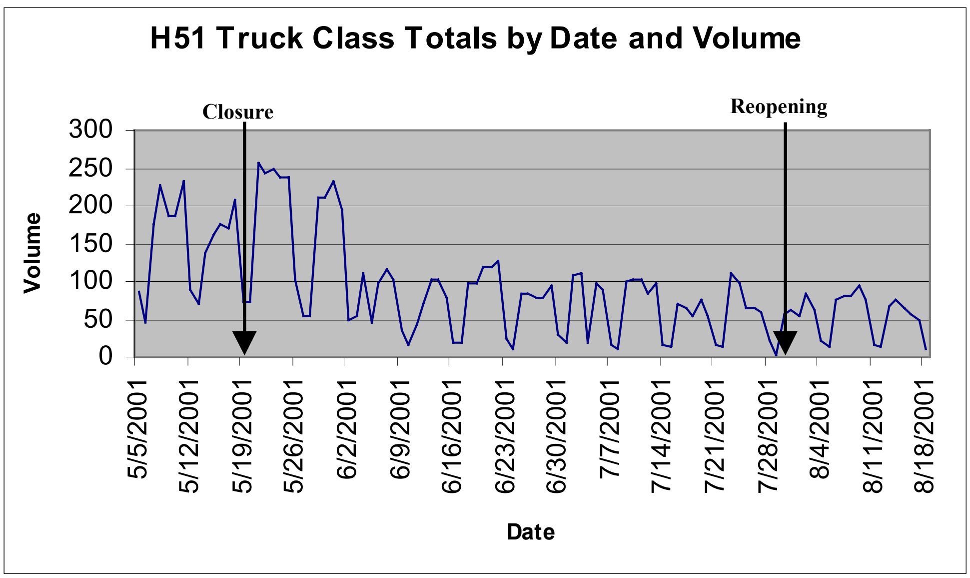

Figure 5.1: Highway 51 daily truck volume by date

Table 5.1: Average daily volume

Average Daily Volume by Period			
	Study Periods 1=before 2=during 3=after		
Site	1	2	3
Ehlen Road	115	143	291
H51	146	82	49
I-5	2998	3039	3225

After an initial downward shift in volume at closure, the traffic volume pattern on Ehlen Road exhibited a continuous upward trend through closure and after reopening (see Figure 5.2)[1]. Average daily volumes on Ehlen Road reflected this upward trend. Truck volumes on I-5 are high enough that an increase of several hundred vehicles would be necessary to chart a noticeable difference. Over the entire study period average daily volumes on I-5 increased by seven percent, with little change between study periods.

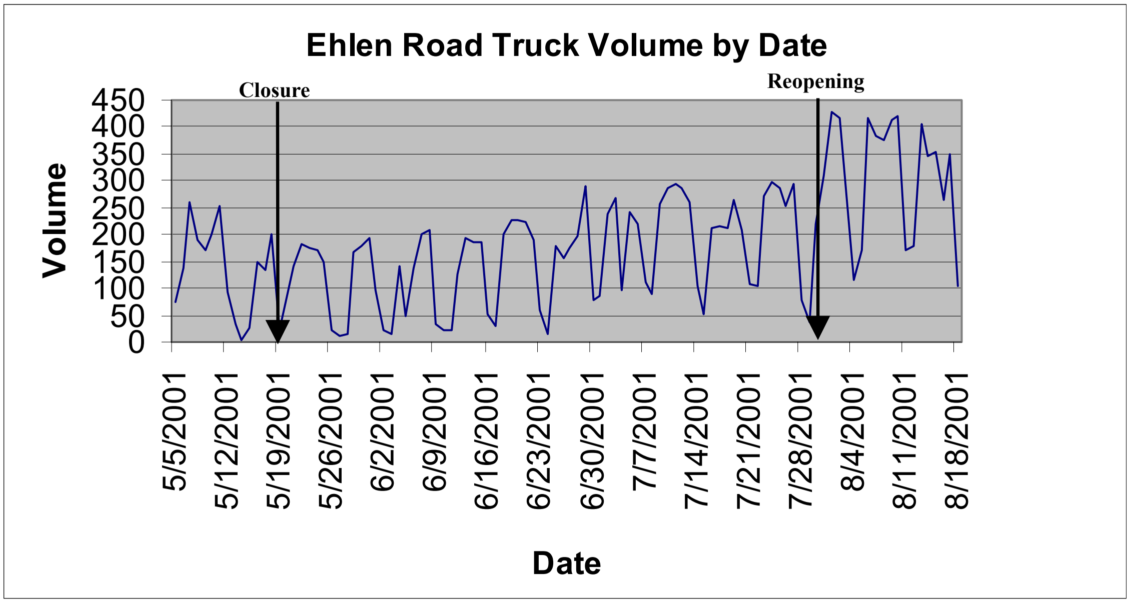

Figure 5.2: Ehlen Road daily truck volume by date

The lack of diversionary evidence was further supported by a comparison of mean gross vehicle weights per site (see Table 5.2). The changes in mean GVW did not follow a consistent pattern across the three sites:

- The Highway 51 mean GVW decreased from baseline to closure and declined again after the Woodburn scale reopened.
- I-5 followed the expected pattern with a 0.4 percent increase in mean from baseline to closure and a 1.2 percent reduction after reopening.
- The Ehlen Road mean GVW increased 5.2 percent after scale closure, and then increased another 12.0 percent after reopening of the I-5 Woodburn scale. The number of vehicles in the preclosure period (15 days) versus the post closure period (18 days) varied by 2,929, a considerable difference given the total average daily frequency of 183.

Thus only the I-5 site followed the expected pattern portrayed in Figure 4.1.

[1] To reinforce the exploration of this trend, data was gathered and plotted for Ehlen Road for two months beyond the study period. The pattern of higher than average truck volumes continued.

Table 5.2: Mean GVW by study period

H51

Mean GVW by Study Period Class 5-13			
Study Periods 1=before 2=during 3=after	Mean	N	Std. Deviation
1	41347.87	1032	14266.6401
2	33161.04	3791	11784.4599
3	28022.72	757	8924.3609
Total	33978.08	5580	12572.2061

I-5 Northbound

Mean GVW by Study Period Class 5-13			
Study Periods 1=before 2=during 3=after	Mean	N	Std. Deviation
1	52988.64	44976	18608.4639
2	53204.84	221882	19036.5285
3	52552.65	58057	19079.5441
Total	53058.38	324915	18987.1163

Ehlen Road

Mean GVW by Study Period Class 5-13			
Study Periods 1=before 2=during 3=after	Mean	N	Std. Deviation
1	39746.92	1658	19545.4600
2	41805.41	12406	21458.2200
3	46837.04	4587	25119.7100
Total	42859.89	18651	22380.0300

A difference in means test was conducted to determine whether the changes in GVW observed at the I-5 Woodburn location were statistically significant. A 95 percent confidence interval was calculated as follows:

$$CI_{95} = (\overline{X}_1 - \overline{X}_2) \pm 1.96 * \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}, \qquad \textbf{(5-1)}$$

where

- $\overline{X}_1$ = the mean GVW for period 1;
- $\overline{X}_2$ = the mean GVW for period 2;
- 1.96 = the critical value from the standard normal distribution associated with the 95 percent confidence level;
- σ_1^2 = the variance of GVW for period 1;
- σ_2^2 = the variance of GVW for period 2;
- n_1 = the number of sample vehicles in period 1;
- n_2 = the number of sample vehicles in period 2.

The differences in GVW means and confidence intervals for the I-5 site are presented in Table 5.3. Although the changes in mean GVW on I-5 were quite small, they were found to be statistically significant, given the large sample size.

Table 5.3: Differences in I-5 GVW means, by study period

Comparison	Difference in Mean (lbs)	Confidence Interval*
Closure v. Pre-closure	216	189.3
Post-closure v. Closure	-652	147.3
Post-closure v. Pre-closure	-436	231.7

*Calculated at the 95th percentile

Mean GVW on I-5 increased about 200 pounds during the closure period. While the increase was slight in proportion to the weight of trucks, it was statistically significant. After the scale was re-opened, mean GVW declined by approximately 650 pounds, which was also statistically significant. Finally, post-closure mean GVW was about 440 pounds less than the pre-closure GVW mean, a difference that was also statistically significant.

5.2 ENFORCEMENT

The results of cross-tabulating the incidence of overweight vehicles at each site per study period are presented in Table 5.4 for vehicle Classes 3-13 (5-13 for I-5). Overweight vehicle occurrences are labeled as 1, non-overweight occurrences as 0. Data from the Highway 51 WIM facility indicated no overweight traffic, while the Ehlen Road overweight vehicle percentages increased significantly over the course of the study.

On I-5 the percentage of overweight vehicles increased from 2.27 percent in the pre-closure period to 3.67 percent during the closure period, an increase of 61.2 percent. Following the reopening of the Woodburn scale, the percentage of overweight vehicles declined to 3.19 percent, a reduction of 13.1 percent. All of the changes were statistically significant at the 95 percent confidence level and were consistent with expectations.

Table 5.4: Comparison of overweight and non-overweight vehicle counts

Highway 51 Class 3-13

Crosstabulation by Weight Variable (Study Periods: 1 = before closure, 2 = during closure, 3 = after closure)

		Weight Variable 0 (not overweight)	Weight Variable 1 (overweight)	Total	Weight Variable 0 as % of total	Weight Variable 1 as % of total
Study Periods	1	2193	0	2193	100.00%	0.00%
	2	5987	0	5987	100.00%	0.00%
	3	887	0	887	100.00%	0.00%
Total		9067	0	9067	100.00%	0.00%

I-5 Northbound Class 5-13

		Weight Variable 0 (not overweight)	Weight Variable 1 (overweight)	Total	Weight Variable 0 as % of total	Weight Variable 1 as % of total
Study Periods	1	43954	1022	44976	97.73%	2.27%
	2	213740	8142	221882	96.33%	3.67%
	3	56203	1854	58057	96.81%	3.19%
Total		313897	11018	324915	96.61%	3.39%

Ehlen Road Class 3-13

		Weight Variable 0 (not overweight)	Weight Variable 1 (overweight)	Total	Weight Variable 0 as % of total	Weight Variable 1 as % of total
Study Periods	1	2163	75	2238	96.65%	3.35%
	2	13662	798	14460	94.48%	5.52%
	3	6252	489	6741	92.75%	7.25%
Total		22077	1362	23439	94.19%	5.81%

Patterns of overloading on I-5 are shown in greater detail in Table 5.5, which provides a breakdown by vehicle class and by participation in ODOT's Green Light program. The bottom rows of the table contrast the percentage of overweight vehicles for AVI-equipped Green Light participants and the non-AVI-equipped remainder of the sample. Among the AVI-equipped vehicles the incidence of overloading increased from 2.07 percent in the pre-closure period to 3.18 percent during closure, a gain of 49.8 percent. Following scale reopening, overloading among AVI-equipped vehicles declined only slightly (-1.3 percent), to 3.06 percent.

For vehicles without AVI transponders, the incidence of overloading increased from 2.34 percent in the pre-closure period to 3.86 percent in the closure period, a gain of 65.0 percent. Following reopening of the Woodburn scale, overloading then declined 16.1 percent to 3.24 percent.

Table 5.5: Changes in proportion of overweight vehicles by vehicle class and AVI status

I-5 Northbound

Crosstabulation by Vehicle Class, Weight, and AVI Variables with Significance Test Results (Study Periods: 1 = before closure, 2 = during closure, 3 = after closure)

			Overall Data			Overall Outcomes*			AVI Data			AVI Outcomes*			Non-AVI Data			Non-AVI Outcomes*		
Vehicle Class			1 = Over-weight occurences	Total	1 as % of Total	Before/During	During/After	Before/After	1 = Over-weight AVI occurences	Total	1 as % of total	Before/During	During/After	Before/After	1 = non-AVI overweight	non-AVI Total	1 (as % of total)	Before/During	During/After	Before/After
5	Study	1	24	2929	0.82%				1	803	0.12%				23	2126	1.08%			
	Periods	2	150	15258	0.98%				7	3858	0.18%				143	11400	1.25%			
		3	38	4258	0.89%				1	1086	0.09%				37	3172	1.17%			
	Total		212	22445	0.94%				9	5747	0.16%				203	16698	1.22%			
6	Study	1		1451	0.00%					210	0.00%				0	1241	0.00%			
	Periods	2		7997	0.00%					927	0.00%				0	7070	0.00%			
		3		2221	0.00%					299	0.00%				0	1922	0.00%			
	Total			11669	0.00%					1436	0.00%				0	10233	0.00%			
8	Study	1	7	2132	0.33%					171	0.00%				7	1961	0.36%			
	Periods	2	68	11308	0.60%				1	791	0.13%				67	10517	0.64%			
		3	18	3248	0.55%					208	0.00%				18	3040	0.59%			
	Total		93	16688	0.56%				1	1170	0.09%				92	15518	0.59%			
9	Study	1	9	645	1.40%	+			1	118	0.85%	+			8	527	1.52%	+		
	Periods	2	113	3368	3.36%		-		25	692	3.61%				88	2676	3.29%		-	
		3	15	867	1.73%				6	224	2.68%				9	643	1.40%			
	Total		137	4880	2.81%				32	1034	3.09%				105	3846	2.73%			
10	Study	1	1	19	5.26%	+			1	7	14.29%				0	12	0.00%	+		
	Periods	2	37	161	22.98%				10	35	28.57%				27	126	21.43%		-	
		3	10	37	27.03%			+	9	22	40.91%				1	15	6.67%			
	Total		48	217	22.12%				20	64	31.25%				28	153	18.30%			
12	Study	1	25	1045	2.39%	+			4	301	1.33%	+			21	744	2.82%			
	Periods	2	219	5222	4.19%		+		93	1658	5.61%				126	3564	3.54%			
		3	62	1428	4.34%			+	37	532	6.95%			+	25	896	2.79%			
	Total		306	7695	3.98%				134	2491	5.38%				172	5204	3.31%			
13	Study	1	955	36754	2.60%	+			222	9473	2.34%	+			733	27281	2.69%	+		
	Periods	2	7555	178568	4.23%		-		1553	46576	3.33%				6002	131992	4.55%		-	
		3	1711	45998	3.72%			+	398	12361	3.22%			+	1313	33637	3.90%			+
	Total		10221	261320	3.91%				2173	68410	3.18%				8048	192910	4.17%			
All Classes	Study	1	1021	44975	2.27%	+			229	11083	2.07%	+			792	33892	2.34%	+		
	Periods	2	8142	221882	3.67%		-		1689	54537	3.10%				6453	167345	3.86%		-	
		3	1854	58057	3.19%			+	451	14732	3.06%			+	1403	43325	3.24%			+
	Total		11017	324914	3.39%				2369	80352	2.95%				8648	244562	3.54%			

* Statistically significant changes in the proportion of overweight vehicles are indicated in these columns. A "+" indicates a significant increase in overweight proportion for the period, while a "-" indicates a significant

It is apparent that the incidence of overloading was nominally lower in each period for AVI-equipped vehicles. Tests of the difference between AVI and non-AVI overloading found that the difference was significant only during the closure period. Thus it can be concluded that Green Light program participants were less likely to be overloaded during scale closure than non-participatory vehicles.

Results with respect to vehicle type in Table 5.5 showed that those in class 13 (five axle tractor-trailers), which account for about 80 percent of the sample, exhibited a somewhat higher propensity to exceed the weight limits than the remaining vehicle classes.[2] This was true although the period-specific shifts in overloading proportions were essentially the same as for the overall population. Among Green Light program participants, only vehicle classes 9 (a four axle 3S-1) and 12 (a five axle 2-S1-2) exhibited significant upward shifts in overloading during scale closure. Among vehicles not participating in the Green Light program, a significant upward shift was also observed in class 10 (a single unit four axle vehicle, SU4). In all remaining classes the observed changes in overloading incidence were found to be insignificant.

Finally it is worth noting that the incidence of weight violations on I-5 did not return to pre-closure levels following the reopening of the Woodburn scale. This result holds within vehicle classes and for both Green Light and non-Green Light program participants. Given what is known about the responsiveness of overloading vehicles to weigh station operations, this finding was unexpected.

[2] The most common truck operating in Oregon is a five axle 3S-2, vehicle class 11. The in-road WIM facility on I-5 northbound grouped this class 11vehicle with class 13 vehicles (5ax combinations) under class 13. Vehicle class 12, a 2-S1-2 axle combination, registered separately.

6.0 CONCLUSIONS

In response to the question of evasion patterns in the I-5 corridor, the evidence does not suggest a tendency toward diversion from I-5 to the bypass routes. The change in enforcement resulting from the 70-day closure of the northbound I-5 Woodburn scale facility did not result in a substantial shift in truck volume.

Ehlen Road and Highway 51 data indicate various potential functional relationships. As evinced by the increase in average daily volume and total volume, Ehlen Road truck counts were not impacted by closure of the I-5 scale. Additional graphing of volume by vehicle class showed only class 3 vehicles exhibiting the predicted pattern of reduction at closure and increase after reopening. Ehlen Road did not appear to be functioning as a bypass route. Seasonal variations in truck traffic in this agricultural setting may have been affecting traffic patterns. Over the course of the study period the change in Highway 51 truck volumes more closely resembled the expected traffic volume patterns. The lack of a recovery in volume on Highway 51 after reopening suggested either a reaction delay beyond 20 days or a different functional relationship to I-5.

The effect of a change in enforcement on loads showed some significance on I-5 for the most common vehicle types and axle configurations. Overall, the impact of closure was not pronounced. How meaningful are the subtle variations on I-5? The increase in overweight occurrences was higher than that found by Cunagin (*1997*) in Florida at fixed scales, but well below the change observed by Fepke (*1994*).

There are several possible explanations for the relatively modest shift in the incidence of overloading observed in this study. First, state-by-state weight enforcement data submitted to FHWA indicate that Oregon has pursued weight enforcement more aggressively than other states, with relatively more weighings and relatively stiffer fines for overweight violations (see Appendix A). Over time Oregon's weight enforcement program – i.e., its strong commitment to well-staffed fixed scales and widespread WIM deployment, coupled with its weight-mile tax – has likely given it a reputation for paying more careful attention to preserving its roadways. In such an enforcement climate, a temporary suspension of weighing activity could be expected to yield less of a change in overloading practices. In addition, trucker awareness of WIM operational characteristics – the knowledge that WIM scales operate independent of an open fixed scale – may influence overloading decisions.

Second, the study showed that participants in the Green Light program were less likely to overload during the northbound I-5 Woodburn scale closure than non-participants. Given that Green Light program vehicles comprised about 25 percent of those sampled, the effect of the program on compliance deserves consideration. It may be that self-selection effects have resulted in a greater likelihood of the more compliance-inclined motor carriers choosing to participate in the program. Alternatively, program participants who see a timesaving from preclearance may be less inclined to jeopardize such benefits by engaging in overloading, even when weighing activity is temporarily suspended. Both of these interpretations may be relevant, given observations on the relative incidence of overloading by Green Light program vehicles before, during and after scale closure.

Third, it should be recognized that I-5 serves as the major North American West Coast freight corridor. For interstate and international shipments, weight enforcement will be encountered at a number of locations en route. The suspension of weighing activity at a single location will thus likely yield less of a response when it is known that enforcement activity continues to be maintained elsewhere along the corridor.

With respect to the question motivating this study – Does the existence of weight enforcement act as a deterrent to overloading? – our findings are affirmative. The small but statistically significant change in the percentage of overweight vehicles on I-5 indicate that there is a propensity amongst truckers to react to changes in enforcement. While the short-term trucker reaction to changes in enforcement were minimal, it appears that the broader enforcement environment in Oregon and along the entire I-5 corridor, and the widespread participation in pre-clearance programs, do act to deter overloading.

In the more general context of enforcement, there are a number of relevant considerations that reside outside the scope of this study: 1) the deployment strategies that maximize effective enforcement for a given commitment of resources; 2) the appropriate penalties for weight violations that effectively relate the economic incentives to overload and the consequential damage to roadways; 3) the extent of compliance and concern for impacts associated with Extended Weight permits granted to trucks; and 4) the optimal investment of state resources in weight enforcement activity, wherein marginal enforcement costs are just offset by marginal avoided roadway damage.

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APPENDICES

APPENDIX A

ECONOMICS OF OVERLOADING AND THE EFFECT OF WEIGHT ENFORCEMENT: ANALYSIS OF STATE DATA

In principle, freight carriers are motivated to set load weight levels that will yield maximum profits. In this context they will exceed legal weight limits to the point where additional revenues obtained from overloading are just offset by additional costs, including the expected penalty from detection through weight enforcement activity. Focusing on operating revenues and costs, the net operating profit per mile to the overloading carrier can be represented as follows:

$$\boldsymbol{\pi = r * (W_{limit} + W_{excess}) - P_d * f(W_{excess}) - c * (W_{limit} + W_{excess})} \qquad \textbf{(1)}$$

where

- r = revenue per ton-mile;
- W_{limit} = the legal load limit, in tons;
- W_{excess} = the load in excess of the legal limit, in tons;
- P_d = the probability per mile of detection by weight enforcement activity;
- $f(W_{excess})$ = the penalty associated with overloading, which is defined to be a function of the level of overloading;
- c = operating costs per ton-mile.

For the sake of simplicity, both the revenue and cost components of Equation 1 are defined to be linear.

First order conditions for maximizing operating profits per mile from overloading are obtained by differentiating Equation 1 with respect to excess load, or

$$\boldsymbol{\partial \pi / \partial W_{excess} = r - P_d f'(W_{excess}) - c = 0} \qquad \textbf{(2)}$$

or

$$\boldsymbol{r = P_d f'(W_{excess}) + c} \qquad \textbf{(3)}$$

where

$$\boldsymbol{f'(W_{excess}) = \partial f(W_{excess}) / \partial W_{excess}}$$

Equation 3 indicates that operating profits per ton-mile are maximized when the marginal revenue from overloading is equal to the marginal additional operating cost plus the marginal expected penalty from detection through weight enforcement. As can be seen, the expected penalty is comprised of two elements. The first, P_d , is an indicator of the intensity of weight enforcement activity, while the second, $f'(W_{excess})$, reflects the severity of the marginal fine imposed on a detected overloader. Thus, state highway officials can seek to reduce overloading activity through increased enforcement, stiffer penalties, or both.

The relative emphasis on enforcement intensity and penalties among states varies considerably, as shown in Figure A-1. Data represented in the figure are for 1999 and are derived from state weight enforcement reports to the Federal Highway Administration (FHWA), an FHWA-reported compendium of state penalties for a 4,000 lb. weight violation, and FHWA estimates of truck vehicle miles traveled (VMT) on freeways and other principal arterials.[1] The horizontal axis in the figure represents the penalty for weight violation, while the vertical axis represents the number of weighings per million vehicle miles. The scales of both axes are indexed at mean values equaling 100.

Four weight enforcement regimes are apparent in Figure A1. The first includes states that combine relatively small penalties with relatively extensive enforcement (e.g., Louisiana, Colorado, Mississippi, Idaho, Virginia, North Carolina, and West Virginia). The second category includes states that combine relatively low levels of enforcement with relatively high penalties (e.g., Minnesota, Pennsylvania, Michigan, Illinois, Rhode Island, and Arkansas). The third category includes states that combine relatively high penalties with relatively intensive enforcement (e.g., Arizona, Missouri, Oregon, South Dakota, and Utah, with Oregon taking the most balanced approach). The final category includes states that combine relatively small penalties with relatively low levels of enforcement (e.g., Vermont, Maine, Nebraska, and Georgia).

Which enforcement regime, if any, is relatively more effective in deterring overloading is essentially an empirical question. Given the conceptual framework and the differential enforcement practices described above, a regression model was estimated relating overweight citations issued in the 48 covered states to enforcement intensity, overweight penalties and revenue potential from overloading. The general specification of the regression is as follows:

$$\textbf{Ln Citations} = \textbf{f(Ln Weighings, Ln Fine, Ln VMT, Ln Value per Ton)} \qquad \textbf{(4)}$$

where

Ln Citations	=	the log of the number of overweight citations issued in 1999;
Ln Weighings	=	the log of the number of vehicles weighed in 1999;
Ln Fine	=	the log of the penalty for a 4,000 lb. overload in 2000.
Ln VMT	=	the log of truck VMT on freeways and principal arterials in 1999;
Ln Value per Ton	=	the log of the value of truck shipments per ton in 1997.

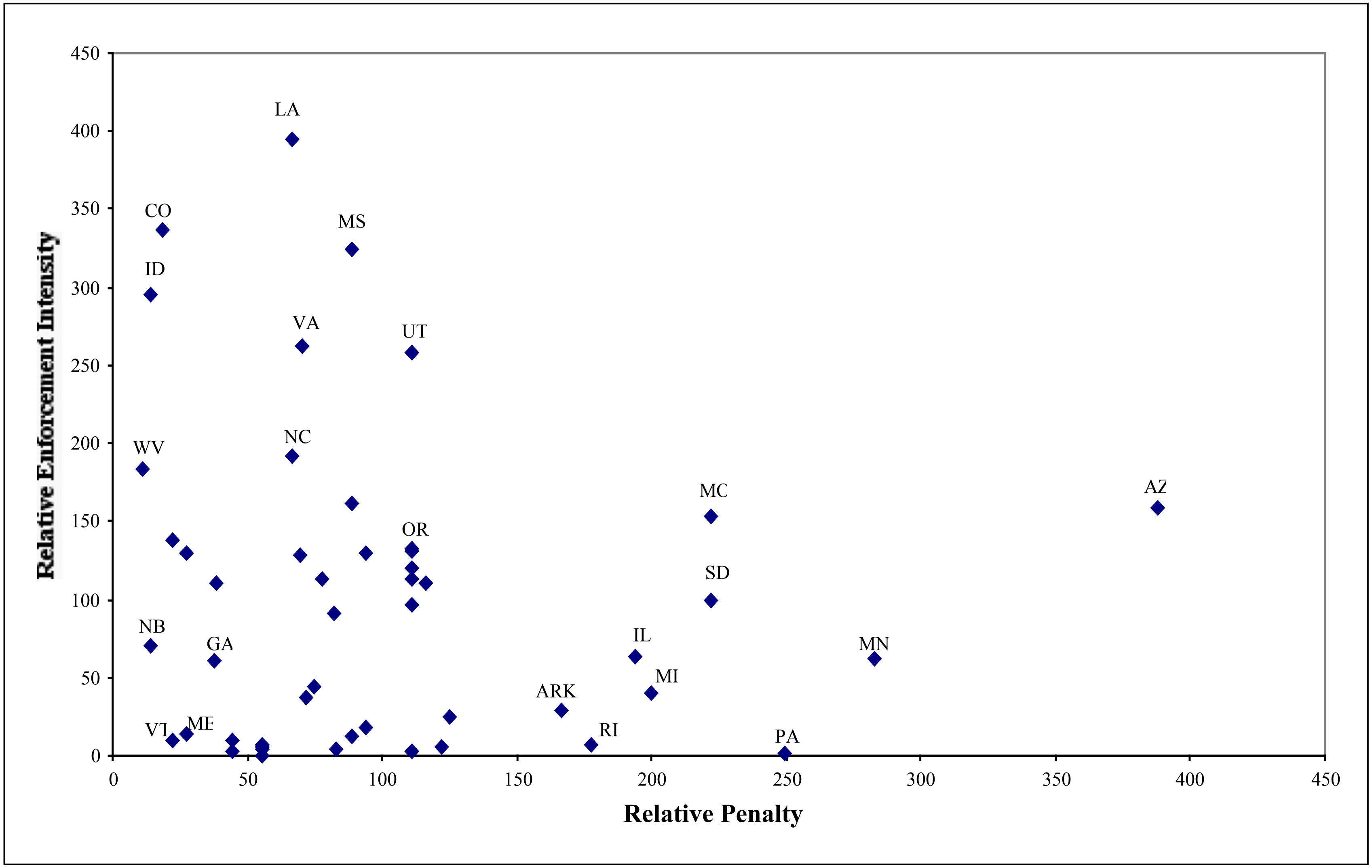

Figure A-1: Relative state weight enforcement intensity and penalties for weight violations

Data sources for all but the final variable are explained in Footnote 1. Value per ton data by state were obtained from the 1997 Commodity Flow Survey conducted by the U.S. Census Bureau.[2] Variables in the regression are specified in log form to allow interpretation of the parameter estimates as elasticities and to avoid heteroskedasticity.

The expected effects of the independent variables on citations are as follows. Holding VMT and other factors constant, we expect citations to increase with the number of weighings, reflecting the increased likelihood of detection of overweight activity. Higher fines are expected to have a deterrent effect on overloading and should therefore be inversely related to the number of citations issued. Holding other factors constant, the number of citations should increase with VMT, given that such growth implies a reduction in the perceived probability of detection. Value per ton shipped is included to represent revenue potential, with the expectation that greater revenue should lead to more overloading activity and, consequently, more overweight citations.

Regression results are presented in Table A-1. Two equations were estimated based on alternative treatment of the number of vehicles weighed. Model 1 specifies the total number of weighings while Model 2 distinguishes between weighings on fixed location and portable/semi-portable scales.[3] Focusing first on Model 1, the results indicate that fines do act to deter overloading, although their effect is relatively inelastic. For example, a 10 percent fine increase is estimated to reduce the number of citations by 2.86 percent. A similar effect is found for weighings, where a 10 percent increase is estimated to reduce the number of citations by 2.59 percent. A more elastic relationship is found for VMT, where a 10 percent increase is estimated to result in an 8.85 percent increase in citations. A moderate elasticity effect is estimated for the value of shipments per ton, but it is not statistically significant.

Turning to Model 2, the estimated fine elasticity is about 20 percent smaller than before and is no longer significant. The estimated elasticities for fixed location and portable scale weighings are interesting. Although the elasticity for portable weighings is about the same as the combined elasticity in Model 1, it is about six times greater than the elasticity estimated for fixed location weighings. This result is consistent with much of the previous work on enforcement deployment strategies, which concludes that weighing at fixed locations is much less effective than at variable locations with portable scales (*Fekpe and Clayton 1994*). This is because fixed weigh station operations are quickly communicated and easily evaded by motor carriers, either by pulling off the road or by diverting to alternate routes (*Cunagin, et al. 1997; Grundmanis 1988*).[4] The estimated VMT elasticity in Model 2 is about 15 percent greater than its Model 1 counterpart, indicating that the growth of citations is nearly proportionate to the growth of truck VMT. Finally, as in Model 1, the estimated effect of value per ton is not significant.

Table A-1: Enforcement model parameter estimates*

(Dependent Variable = Ln Overweight Citations)

Variable	Mean** (St. Dev.)	Model 1	Model 2
Ln Fine	$182.1 (138.8)	**-.286 (-2.00)**	-.238 (-1.56)
Ln Weighings$_{total}$	2,081,400 (2,751,500)	**.259 (3.62)**	--
Ln Weighings$_{fixed}$	2,047,500 (2,753,000)	--	.041 (1.80)
Ln Weighings$_{portable}$	33,877 (57,926)	--	**.251 (2.75)**
Ln VMT (millions)	3,855.1 (3,755.2)	**.885 (6.23)**	**1.033 (7.79)**
Ln Value per Ton	$603.0 (221.4)	.382 (1.11)	-.019 (-.05)
Constant	--	-2.747 (-1.23)	-1.018 (-.46)
R^2	--	.78	.76
n	48	48	48

* Coefficients in bold type are statistically significant at the .05 level.

** Means and standard deviations are reported in nominal values.

Returning to the initial question of enforcement strategy, the regression results indicate that the relative consequences of emphasizing enforcement intensity or overweight penalties are about the same in terms of deterring overloading activity. The enforcement intensity effect, however, is found to be largely associated with the use of portable/semi-portable scales, which accounted for less than two percent of vehicle weighings reported by the subject states in 1999.[5]

There is substantial evidence that overweight fine structures are well below marginal revenues from overloading, as well as estimates of the marginal cost of road damage from overloading (*Bisson and Gould 1989; Casavant and Lenzi 1993; Church and Mergel 2000; Euritt 1987*). Thus there is a basis for states to either increase fines or intensify enforcement, with the former likely being more cost-effective given the findings of this note.

APPENDIX A FOOTNOTES

1. Data on the number of vehicles weighed and weight violation penalties are posted on the FHWA web site at **http://www.ops.fhwa.gov/freight/regulate/sw/index.htm**. Two states (Alabama and Indiana) are excluded because their weight penalty schedules do not report a fixed value for a 4,000 lb. overload. Truck VMT data are taken from FHWA's Highway Statistics 1999, Section V, which is posted at **http://www.fhwa.dot.gov/ohim/hs99/roads.htm**. The enforcement intensity scale in the figure should be interpreted with caution because the highway classification used to construct the VMT base measure does not directly correspond to state highway systems.

2. The 1997 Commodity Flow Data by state are reported at **http://www.bts.gov/ntda/cfs/cfsstate.html**.

3. Five states (Maine, Massachusetts, New Hampshire, New York, and Rhode Island) reported zero weighings on fixed location scales. In order to take the logarithms, the values for these states were set at .1.

4. While it is not the purpose of this research note to address the overall effectiveness of state weight enforcement practices, it should be acknowledged that considerable evasion exists. For example, among the 48 states analyzed here, data used in the regressions show that only .7 percent of the vehicles weighed were issued overweight citations. Church and Mergel (*2000*) refer to analysis of data collected by weigh-in-motion scales for the Highway Performance Monitoring System that show between 10 and 20 percent of vehicles exceeding legal weight limits. While an unknown share of these overweight vehicles is legally operating with permits, it would probably not be an exaggeration to claim that evasion approaches 90%.

5. It would be wrong to conclude from these results that fixed location weighing is ineffectual in deterring overloading. Frequently, enforcement practice involves deployment of portable scales on by-pass routes to intercept vehicles attempting to evade operations at fixed weigh stations. Were the fixed weigh stations not operating, the effectiveness of portable scales would certainly be lessened. The more relevant enforcement question (which is beyond the scope of this note) is the determination of the most effective deployment strategy combining fixed location and portable weighings, recognizing that the cost per vehicle weighed is substantially greater for portable scales.

APPENDIX B

VEHICLE CLASS DEFINITIONS AS DEFINED BY OREGON DEPARTMENT OF TRANSPORTATION

Vehicle Class	Axle Combination	Vehicle Description
1	2	Cars, vans, pickups
2	2+	Light vehicles with trailers
3	2axSU	Two axle, single unit
4	2	Two axle busses
5	SU3	Three axle, single units
6	2-S1	Three axle combinations
7	3	Three axle busses
8	2-S2, 2-2	Four axle combinations
9	3-S1	Four axle combinations
10	SU4	Four axle, single units
11	3-S2	Five axle tractor-trailer
12	2-S1-2	Five axle twins
13	2-3, 3-2	Other five axle combinations
14	3-S1-2	Six axle combinations
15	2-2-2, 2-S1-3	Other six axle combinations
16	2-S1-2-2	Triple trailers
17	3-S2-2, 2-2-3, 3-2-2, …	Other seven axle combinations
18	3-S2-3, 3-S1-2-2, …	Eight axle combinations
19		Nine or more axles combinations